UNIVERSITI PUTRA MALAYSIA

REDUCED RANK TECHNIQUE FOR JOINT CHANNEL ESTIMATION AND JOINT DATA DETECTION IN TD-SCDMA SYSTEMS

ALI KAMIL MARZOOK

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By

ALI KAMIL MARZOOK

Thesis Submitted to the School Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

May 2013

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DEDICATION

To my ever-encouraging parents…

To my altruistic and beloved wife (Alya)…

To my lovely brother (Jassim) and lovely sisters…

To my lovely sons (Zahraa, Mohammad, Zainab and Mahdi)…

To my understanding parent in laws (Uncle Ghazi Darweesh)…

To my supportive siblings…

To my friends…

To every striving muhsin person who is constantly improving aspects of life…

To those who are compassionate towards achieving perfection…

To the consistent pursuers of knowledge aiming for positive change…

A special contribution to my home country Iraq and to Malaysia;

with lots of gratitude…

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

REDUCED RANK TECHNIQUE FOR JOINT CHANNEL ESTIMATION AND DATA DETECTION IN TD-SCDMA SYSTEMS

By

ALI K. MARZOOK

May 2013

Chairman: Assoc. Prof. Alyani Binti Ismail, PhD

Faculty: Engineering

Time Division–Synchronous Code Division Multiple Access (TD-SCDMA) has been classified as one of 3G wireless communication systems in the last years. The physical layers of this system have adopted several advanced technologies, such as: joint detections, uplink synchronization, and smart antennas, making it capable of meeting the requirements of 4G systems directly.

One of the essential parameters that affects the performance and reliability of TD-SCDMA systems in current wireless applications is channel estimation. A novel channel estimation method is presented in this thesis relying on the reduction of the rank order of the total channel matrix **H.** We have exploited the rank deficient of **H** to reduce the number of parameters characterizing the channel matrix and model it with the lower number of parameters that actually require a description of **H**.

The adopted reduced rank technique is based on Singular Value Decomposition (SVD). The proposed method has declared the superiority over the conventional methods that are being used in the current applications of TD-SCDMA systems. The Mean Square Error (MSE) and Bit Error Rate (BER) metrics analyzing the channel matrix precision among the methods is also suggested in this thesis for comparison; Least square (LS), post-processing, and the proposed reduced rank methods.

In addition, the technique is proposed as a new algorithm for joint channel estimation of the multi-cell model based on reduced rank technique handling the active users in serving cell and the strong interferers from the neighboring cells. The new technique can improve the TD-SCDMA systems with low rank order processing and low computation complexity. Unlike the conventional models of multi-cell channel parameters, the channel matrix of reduced rank multi-cell model has been estimated in parsimony to involve the detected users from the serving and neighboring cells. This proposed method can acquire and claim a remarkable improvement in the performance especially under the worst interference situations.

Finally, a smart antenna system has been merged with reduced rank technique to introduce a robust performance of TD-SCDMA system. A low effective rank order of ST channel can be adopted to construct the low rank based receiver with low complexity and remarkable performance.

The simulation results prove that the reduced rank technique of TD-SCDMA systems can lead to considerable system performance enhancements and can efficiently

mitigate interference. In single cell networks, rank two based detector has the pioneered order along SNR and it introduces improvement about 4 dB gained over the traditional LS full rank based detectors. In multi-cell networks, rank one estimator is suitable for case one of multi-cell and provide 9 dB enhancement over the multi-cell LS estimator while; rank two is more suitable for case two of the multi-cell and provide at least 5 dB enhancement along the SNR axis over the multi-cell LS estimator. Finally in the ST TD-SCDMA system, rank three based detector outperforms traditional LS detector by having 4 dB gains at BER of 10^{-3} with 8 arrays model at 3Km/h. The reduced rank technique is used to control the complexity of channel estimation. The performance of all the schemes are simulated and analyzed by using MatLab 7.9 simulator.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PANGKAT DIKURANGKAN TEKNIK UNTUK ANGGARAN SALURAN BERSAMA DAN BERSAMA PENGESANAN DATA DALAM SISTEM TD-SCDMA

Oleh

ALI K. MARZOOK

Mei 2013

Pengerusi: Prof. Madya Alyani Binti Ismail, PhD

Fakulti: Kejuruteraan

Time Division-Synchronous Code Division Multiple Access (TD-SCDMA) telah diklasifikasikan sebagai salah satu sistem komunikasi 3G tanpa wayar pada tahun-tahun yang lalu. Lapisan fizikal system ini telah menerima pakai beberapa teknologi canggih, seperti pengesanan bersama, penyegerakan pautan atas dan antenna pintar menjadikan ia mampu memenuhi keperluan sistem 4G secara langsung.

Salah satu parameter terpenting yang memberi kesan kepada prestasi dan kebolehpercayaan sistem dalam aplikasi semasa tanpa wayar TD-SCDMA adalah penganggaran saluran. Satu kaedah novel untuk penganggaran saluran bergantung kepada pengurangan peringkat berpangkat terhadap jumlah saluran matrik **H** telah

dibentangkan di dalam tesis ini. Kekurangan peringkat **H** telah dieksploitasi untuk mengurangkan bilangan parameter yang mencirikan matriks saluran dan memodelkannya dengan bilangan parameter yang lebih rendah yang benar-benar memerlukan penerangan **H**.

Teknik pengurangan pangkat yang digunakan adalah berdasarkan *Singular Value Decomposition* (SVD). Kaedah yang dicadangkan ini telah menyatakan kelebihan berlebihan kaedah konvensional yang sedang digunakan dalam aplikasi semasa sistem TD-SCDMA. The Mean Square Error (MSE) dan Bit Error Rate (BER) metrik menganalisis matriks ketepatan saluran antara kaedah yang juga dicadangkan di dalam tesis ini untuk perbandingan; Least Square (LS), post processing, dan cadangan reduced rank kaedah.

Di samping itu, sebuah algoritma baru telah dicadangkan untuk anggaran saluran bersama untuk model multi-sel yang berdasarkan teknik pangkat dikurangkan pengendalian pengguna aktif dalam melayani sel dan interferers kuat daripada sel-sel jiran. Teknik baru ini dapat meningkatkan sistem TD-SCDMA dengan pemprosesan pangkat rendah dan kerumitan pengiraan yang rendah. Tidak seperti model konvensional parameter saluran multi-sel yang lain, saluran matriks oleh model pengurangan peringkat multi-sel telah dianggarkan untuk melibatkan pengguna yang dikesan dari sel-sel pelayan dan kejiranan. Kaedah yang dicadangkan ini mampu memperoleh dan menuntut peningkatan prestasi yang luar biasa dalam prestasi terutama di bawah situasi gangguan yang terburuk.

Akhirnya, sistem antena pintar telah digabungkan dengan teknik pengurangan peringkat untuk memperkenalkan prestasi yang teguh dalam sistem TD-SCDMA. Saluran ST yang mempunyai keberkesanan kedudukan pangkat yang rendah boleh diguna pakai untuk membina penerima pangkat rendah dengan kerumitan yang rendah dan prestasi yang luar biasa.

Keputusan simulasi membuktikan bahawa teknik pangkat dikurangkan sistem TD-SCDMA boleh membawa kepada peningkatan prestasi sistem yang besar dan cekap boleh mengurangkan gangguan. Dalam rangkaian sel tunggal, pangkat dua pengesan mempunyai perintah itu bersama-sama mempelopori SNR dan ia memperkenalkan peningkatan kira-kira 4 dB mendapat lebih LS pengesan pangkat penuh tradisional berasaskan. Dalam rangkaian multi-sel, pangkat satu penganggar sesuai untuk mana-mana salah satu daripada pelbagai sel dan menyediakan peningkatan 9 dB lebih penganggar LS pelbagai bimbit semasa; pangkat dua adalah lebih sesuai untuk kes dua multi-sel dan menyediakan sekurang-kurangnya peningkatan 5 dB sepanjang paksi SNR lebih penganggar LS multi-sel. Akhirnya pada ST TD-SCDMA sistem, pangkat tiga pengesan pengesan melebihi performa LS tradisional dengan mempunyai keuntungan 4 dB pada BER daripada 10^{-3} dengan 8 barisan model di 3km/h. Teknik pangkat dikurangkan digunakan untuk mengawal kerumitan anggaran saluran. Prestasi semua skim adalah simulasi dan dianalisis dengan menggunakan Matlab 7.9 simulator.

ACKNOWLEDGEMENTS

Of all that exists in the entire universe, my sheer gratitude is dedicated to no other than the Most Compassionate Allah S.W.T. Who had Generously Bestowed me a golden chance to further my doctorate degree in Universiti Putra Malaysia.

I am too touched being fated an ardently obliging beloved wife who is incessantly empowering my drive towards completing the painstaking processes throughout the tribulations of the study. In addition to the dynamic spur of enthusiasm, which is inexplicably bursting from the fierce love I deeply feel for my lovely daughters – towards the betterment of our future life. So goes to other inspiring family members.

Anyhow, all the way through, I am truly indebted to my flexible but efficient supervisor: Associate Professor Dr. Alyani binti Ismail for her clear-cut style of supervision yet promoting students' freedom of ideas expression to stand upright with her securing offer of unwavering support – really, I am among the lucky few. In addition, I wish to express my appreciation to the members of my committee, Professor Dr. Borhanuddin Mohd Ali, Professor Dr. Sabira Khatun, and Dr. Aduwati binti Sali for offering their valuable time and comments.

Besides, I definitely will be missing the campus life especially where my best friends and engineering lab-mates regards, as their existence around is always an experience-enriching one to the meaning and maturation of my colourful life.

I certify that a Thesis Examination Committee has met on 17th May 2013 to conduct the final examination of Ali Kamil Marzook on his thesis entitled "**Reduced Rank Technique for Joint Channel Estimation and Joint Data Detection in TD-SCDMA Systems**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

ALI K. MARZOOK

Date: 17 May 2013

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LIST OF ABBREVIATIONS

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Forth Generation
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BS	Base Station
BSC	Base Station Controller
CDMA 2000	Code Division Multiple Access 2000
CIR	Channel Impulse Response
DCA	Dynamic Channel Allocation
DFT	Discrete Fourier Transform
DL	DownLink
DSP	Digital Signal Processor
DS-UWB	Direct Sequence-Ultra Wide Band
FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
FPGA	Field Programmable Gate Array
GSM	Global System Mobile
ICI	Inter-Cell Interfering
IFFT	Inverse Fast Fourier Transform
IMT-Advanced	International Mobile Telecommunications-Advanced

ISI	Inter symbol Interference
JD	Joint detection
IoT	Internet of Things
ITU	International Telecommunication Union
LOS	Line Of Sight
LS	Least square
LTE	Long Term Evolution
MAI	Multiple Access Interference
MIMO	Multi Input Multi Output
MMSE	Minimum Mean Square Error
MMSE-BLE	Minimum Mean Square Error Block Linear Equalizer
MS	Mobile Subscriber
MSE	Mean Square Error
MVDR	Minimum Variance Distortionless Response
PoC	Push to Talk over Cellular
SIR	Signal to Interference Ratio
SNR	Signal to Noise Ratio
RRC	Root Raised Cosine
SAR	Synthetic Aperture Radar
ST	Space Time
SVD	Singular Value Decomposition
TD-SCDMA	Time Division–Synchronous Code Division Multiple Access
TD	Time Division
TDD	Time-Division Duplex
TSVD	Truncated Singular Value Decomposition

TDMA	Time Division Multiple Access
UL	UpLink
VoIP	Voice over IP
WCDMA	Wideband Code Division Multiple Access
WSN	Wireless Sensor Networks
ZF	Zero Forcing
ZF-BLE	Zero Forcing Block Linear Equalizer

CHAPTER 1

INTRODUCTION

1.1 Background

From the beginning of the first generation (1G) lunch, there has been a tremendous rapid development in mobile services and mobile systems become, with the dawn of a new century, wireless communications has made it increasingly possible for people to communicate anywhere and anytime owing to new services and more sophisticated applications than there used to be [1]. It is predicated that future services in wireless communications systems will increase the popularity of mobile devices and motivating the development of various mobile applications. The rapid growth in data communication has invited the need for high bit rates in the communications systems to provide "wideband" contents such as video and audio streaming [2].

After the 3G systems have been standardized, the interest of the research bodies has gone beyond 3G and 4G systems aiming to operate at a much higher data rate (100Mbps or even 1Gbps) [3]. In order to provide high-data-rate services that deploys the new 4G system applications, communication designers and suppliers have adopted two ways. The first group which has suggested and tried to create new radio access technology, is currently engaged to several research programs such as China's FuTURE and the European MATRICE [4]. One of the principle challenges

they are facing is the monetary issue as billions of dollars are required to build a new cellular system. In addition to that, smooth migration from the old generation to the next generation and matching with the current devices that have the ability to support the new generation is another challenge [5].

Besides that, the second group has proposed the possibility of depending on the current 3G systems infrastructure. They are attempting to improve the system performance by solving the challenges and the open issues and focusing on vigorously push of the boundaries on the maximum rate at which information can be transmitted over the wireless communication systems.

There are many reasons are behind this motivation; the issue of cost involved in the first rank, avoiding the migration and the coexisting problems between the two generation systems. One of the major reasons that has motivated the second group is advanced characteristics found in 3G systems (TD-SCDMA is our system that we will try to develop some of the features) that can be directly applied to 4G systems.

TD-SCDMA system is considered as one of the promising multiple access techniques which can be combined with Time Division (TD). The motivated features of this system such as Time-Division Duplex (TDD) allows the flexible allocation of the ratio between DownLink (DL) and UpLink (UL), which gives it a flexibility of usage to handle both symmetric traffics (such as voice) and asymmetrical services (such as mobile Internet access) [6-8]. Adding to that, the suitability for different

deployment scenarios: from indoor to outdoor and from rural area to dense urban area with user mobility from pedestrian to vehicular. The air interface of 4G will be a mixture of mature technologies used in 3G and newly developed ones targeting higher data rates.

Our vision of a 4G system is to have a set of improved the features of TD-SCDMA systems and exploiting the advanced characteristics such as joint detection and smart antenna, and flexible DL and UL capacity allocation. Besides, solving the problems that are encountered to eliminate their performances with low complexity system and high accuracy outage will make the TD-SCDMA a strong candidate for the evolution of 4G system.

This chapter is organized as follows. Initially, the problem statement of the thesis is discussed. It is followed by the thesis objectives and the scope covered in this thesis. Finally, the organization of the thesis is presented.

1.2 Problem Statement and Motivation

Addressing various challenges and open issues such as, increasing the system capacity, estimating accurate channel with reliable system, managing interference mitigations, achieving higher data rate, etc, guarantees fixable and seamless migration from the present 3G systems to the next 4G systems with applications relying on the infrastructure of the present 3G systems, in order to present efficient

TD-SCDMA systems to deploy the requirement of the future wireless communications, as well as the limitation of the current research for the TD-SCDMA systems performance describe in the next subsections:

1.2.1 Accurate channel estimation with low parameters estimation

One of the essential parameters affecting the performance and reliability of TD-SCDMA systems in current wireless applications is channel estimation. Theoretically, the main concerns in the channel estimators design are the accuracy of the estimation and the simplicity of the hardware. A poor estimation degrades the quality of the existing mobile communication systems, and increases their mean square error measure of the system; in addition to that, increase the BER of multi-user joint detector that based on a provision of precise joint channel estimation.

It is known that the channel estimation in TD-SCDMA systems requires the knowledge of the entire number of channels between the transmitter (mobile station) and the receiver (base station) and vice versa. Usually, this channel is estimated by using an embedded training sequence or midambles (for example, 144 bit in the 1.28 Mbps option of TD-SCDMA systems) in each transmitted slot of data. However, this estimation may be inaccurate on account of the large number of parameters that requires estimation along short training sequence. Moreover, the estimation must be made adaptive to coping with the rapid variations in the physical channel, especially at high users' mobility.

In addition, the estimation of full rank channel matrix parameters requires more processing time; especially with densely populated areas where the planning networks optimizers try to increase the system capacity by sharing the one time slot with large number of users (a maximum of 16 users per time slot), which ultimately increases the number of parameters that are needed to estimate the channel of each user. In contrast, the total channels of entire system will become more complicated and the processing time will be increased.

1.2.2 High interference environments

On the move, as the demand for high data rate mobile applications continues to rise, cellular networks and mobile hardware designers seek to push vigorously the boundaries at the maximum rate where data can be transmitted over wireless communication channels.

The accuracy of channel estimation in TD-SCDMA systems is related to the interference level (inter- and intra- interference). The current channel estimators consider the Inter-Cell Interfering (ICI) signal as white noise added to the intra-interference (Multiple Access Interference (MAI) and Inter symbol Interference (ISI) and fading channel, which together degrades the precision performance of channel estimators. The multi-cell channel estimation is an effective solution to obtain the better knowledge of the Channel Impulse Response (CIR), by including the signals of the strongest interfering users from neighbouring cells into the channel estimation.

In this thesis, the proposed channel estimation method is based on the Singular Value Decomposition (SVD) for multi-cell networks of the TD-SCDMA system tested under 3GPP and ITU standards that describe the channel environments of the TD-SCDMA system at indoor and vehicular channels. The channel matrix of each scenario has correlated coefficients that cause a reduction in the effective number of degree of freedom and the number of estimated parameters that really need it to describe the channel matrix being low. According to the encountered results, the multi-user reduced rank channel estimators have the superiority over the conventional estimators that are currently used in single-cell and multi-cell networks.

1.2.3 High Complexity of Smart Antenna Receiver

The essence of cellular system design is spatial reuse, which allows geographically separated transmitters to make the use of the same time and frequency resources [21]. The need to find solutions that would support the growing number of users of 3G wireless systems including TD-SCDMA systems has stimulated many research groups to explore new techniques to increase the system capacity of the mobile communication systems.

Adding a new dimension in processing (spatial) will increase the parameters of the Space-Time (ST) channel matrix and based on two ranking orders (temporal and spatial) that will be proportional to the complexity of the system and the time channel estimation.

1.3 Research Aims and Objectives

This thesis aims to enhance the performances of the joint channel estimators and the associated multi-user joint detectors in TD-SCDMA systems by proposing a new technique based on singular value decomposition reduced rank algorithm for different types of network scenarios (single and multi-cell networks) and is extended to smart antenna applications under two global standardizations (3GPP and ITU). As such, the main objectives of this thesis are:

1. To develop a mathematical model of the TD-SCDMA signal aiming to increasing TD-SCDMA systems throughout by a new channel estimation process.

2. To optimise the reduced rank technique for the TD-SCDMA system for signal cell network deployments.

3. To maximize the system capacity by inserting 16 users in one time slot.

4. To improve the accuracy of the multi-cell joint channel estimation by taking the signals of users of the neighbouring cells that having a strong interference into channel estimation matrix.

5. To introduce an efficient ST joint channel estimation and data detection and smart antenna system for TD-SCDMA systems.

To meet these aims and objectives, a new technique for joint channel estimation that is based on SVD reduced rank is proposed in this thesis. In the single-cell TD-SCDMA cellular communication systems, the proposed schemes outperforms traditional channel estimation schemes by having 2-4 dB BER gain (depending on the type of channel and the standardization model) and exploiting rank one or two estimation only from the whole channel matrix system. For Multi-cell TD-SCDMA system, the proposed scheme shows significant improvement in terms of user capacity as compared to the conventional scheme with only 5-9 dB BER gain. Finally the proposed method for ST TD-SCDMA system can provide remarkable structure of receiver with low complexity. Rank three based receiver can be adopted for the Indoor channel of 3GPP recommendations with five rank exploited advantage under the conventional full rank; while rank four based receiver can be rely it for vehicular channel.

1.4 Brief Methodology

To achieve the high data rate, user capacity, transmission reliability and bandwidth efficiency in wireless transmission systems, several schemes are proposed in this thesis. The methodology of this thesis is proposed for both real-time visual data transmission and overloaded CDMA systems as illustrated in Figure 1.1.

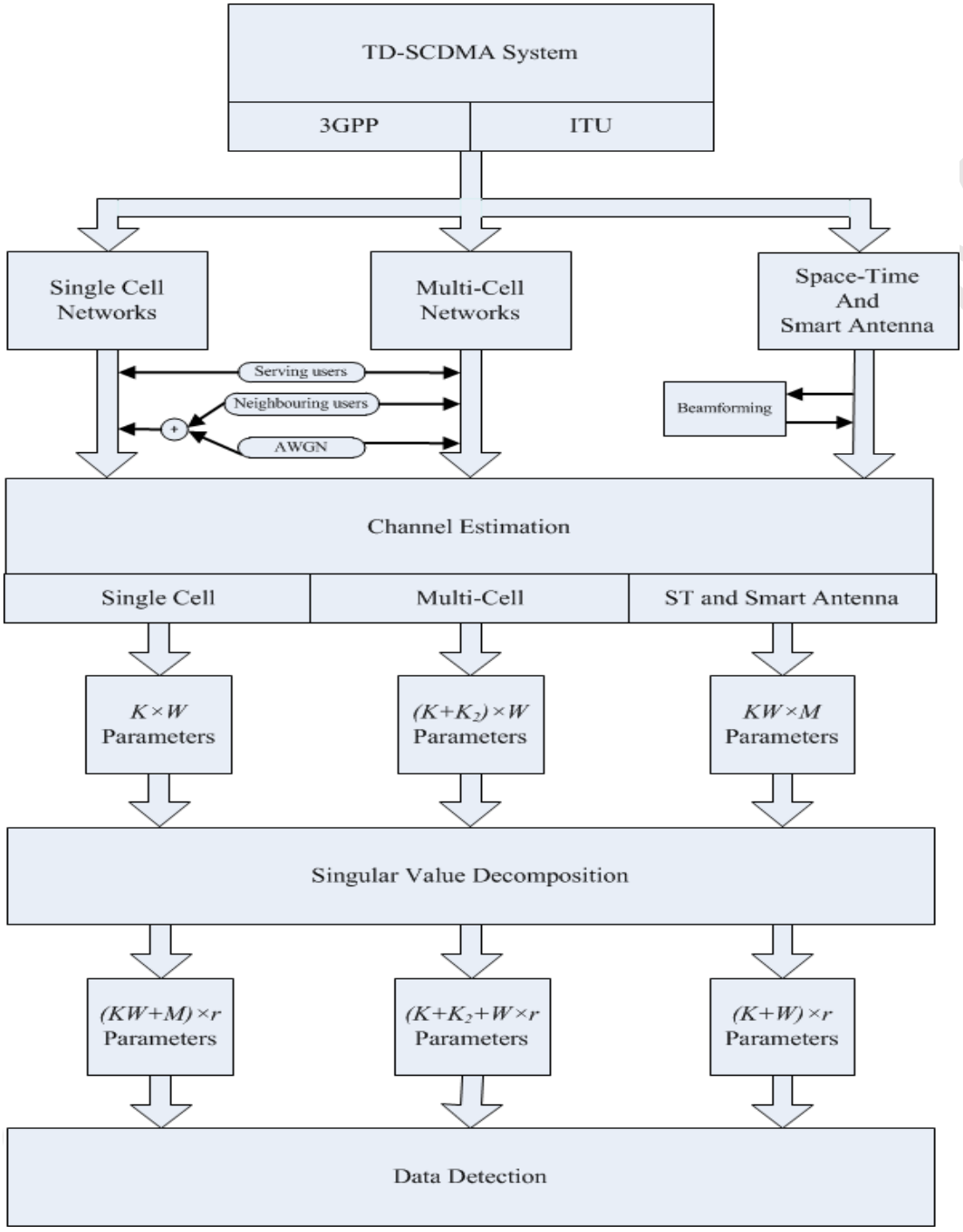

Figure 1.1. Brief Methodology.

The proposed techniques are designed and developed using MATLAB 7.9 (R2009b) and simulated under frequency selective channel and Additive White Gaussian Noise (AWGN) environments for Indoor and Vehicular user's movement channels.

1.5 Thesis Scope

A summary of the scope of this thesis is illustrated in Figure 1.2.

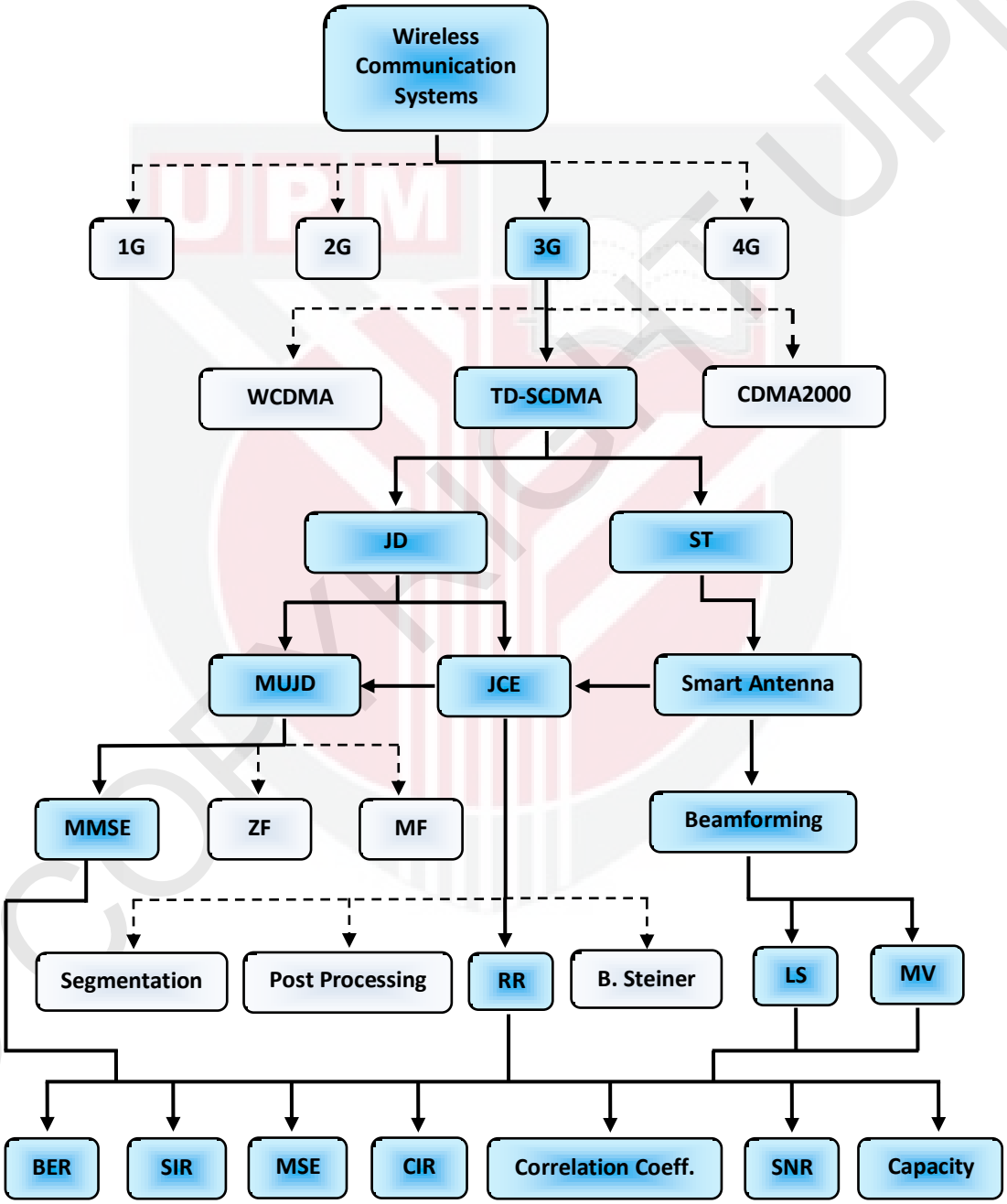

Figure 1.2. Study Module

The direction of flow of the proposed schemes is indicated by the bold lines, whereas the dotted lines indicate related research areas which are out of the scope of this thesis.

1.6 Organization of the Thesis

This thesis addresses the problems and practical issues of joint channel estimation in TD-SCDMA system with intra and inter-cell interference. Comprehensive study for single and multi-cell network deployments will introduce and apply the reduced rank technique for these scenarios and associating the multiuser joint detection systems. The rest of the thesis is organized as follows.

Chapter One provides an introduction and a brief review on the latest joint channel estimation in TD-SCDMA. It also includes the objectives of the study, the scope of the work, and the problem statement.

Chapter Two, the related technical background and literature review are presented in this chapter. The basic concepts of wireless mobile cellular communication systems and their generations with short description to the TD-SCDMA air interface part. The chapter reviews the principles of the important techniques employed in joint channel estimation algorithms. In comparison to the other issues, practical problems associated with these algorithms are also briefly discussed. The structure of TD-

SCDMA receiver with the proposed channel estimation technique is extracted in this chapter. It also presents the motivation of embedded smart antenna technology solution in the future of wireless systems.

In chapter Three the underlying idea of the reduced rank approaches for single cell TD-SCDMA system is introduced. The training and data model of the proposed single-cell joint channel estimation and multi-user joint detection over Additive White Gaussian Noise (AWGN) channels are presented. The effective low rank property of the wireless channel is analyzed. A rank analysis of indoor and outdoor typical propagation environments shows that single cell channel matrix describing the channel in fact low rank. The reduced rank channel model is suggested as a solution to overcome the complexity that resulted from increasing the system capacity by inserting the maximum number of users in one time slots. To make the test more comprehensive, we have involved the two standard systems 3GPP and ITU.

Chapter 4 focuses on the reduced rank estimation which is extended to multi-cell systems. The proposed method can effectively cope with inter-cell interference (ICI) from neighboring cells and multiple access interference occurring because the non orthogonality of training sequence. Furthermore, with respect to the conventional full rank receiver, it has shown that the lower number of rank order that represents the extended multi-cell channel matrix results not only in performing well estimation but also in reduced complexity of the structure of multi-cell based detector.

Chapter 5 presents a new method to reduce the complexity of the ST TD-SCDMA receiver. Reduced rank channel modeling, estimation, and proper rank choice are all detailed. By adopting rank three and rank four, we get simple ST TD-SCDMA receivers architectures for 3GPP standard where their ST parameters are simultaneously determined by a joint optimization criterion. In contrast, rank two and three are optimized for ITU standard recommendations.

Chapter 6 includes conclusions and summarized the thesis, followed by the discussion of the key contribution of the proposed work. There are several directions for future research that have also been suggested for further investigation.

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